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TREATMENT OF REAL TEXTILE WASTEWATER USING SBR TECHNOLOGY: EFFECT OF SLUDGE AGE AND OPERATIONAL PARAMETERS

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Abstract- Textile wastewater is one of the most hazardous wastewater for the environment when discharged without any treatment. Biological treatment technologies have shown encouraging results over the treatment of toxic compounds containing wastewaters. In this study, real textile wastewater (RTW) was treated in a lab scale aerobic sequencing batch reactor (SBR).

The characterisation of RTW showed that this effluent is biodegradable and highly variable, depending on chemicals and techniques used in the production process. COD averaged 1045 mg L^{-1}, electric conductivity (EC) and suspended solids (SS) averaged 4220 µS cm^{-1} and 3160 mg L^{-1} respectively. RTW was treated in an aerobic SBR and the performance of the system was evaluated under different operating conditions with changes in organic loading rate (OLR), sludge age and mixed liquor volatile suspended solids (MLVSS) concentration. The reactor was operated with a total sequence of 24 hours and the total reaction phase (aerobic phase) was kept constant at 22 h in all experiments. Despite the variations in the characteristics of RTW, the reactor achieved proper removal of organic matter, once the acclimation of the microorganisms was achieved. Optimum removal efficiencies of 93.28, 99.41 and 99.9% on COD, colour and SS respectively, could be reached with an OLR of 0.3 kg COD m^{-3} d^{-1}, sludge age of 30 days and MLVSS of 2450 mg L^{-1}. In addition, the treated water meets the Moroccan discharge quality standards. The results indicated that dyes and COD are mainly used by aerobic organisms and aeration improves the performance of SBR system.

Keywords- Real textile wastewater, aerobic sequencing batch reactor, decolorization, COD removal, operational parameters

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Introduction

The textile industry represents an important economic sector worldwide, being responsible for 1.7% of world exportation in 2007, which corresponded to the amount of US$ 238.1 billions [1,2]. Thus, textile industry is one of the most polluting industries which consume big quantities of water (up to 150 L of water to dye 1 kg of cotton) and generates huge amounts of wastewaters. However, this industry discharges wastewater containing various pollutants such as degradable organics, colours, nutrients, pH altering agents, salts, sulphur, toxicants and refractory organics [3]. These pollutants are formed during various stages of the textile manufacturing process, namely singeing, desizing, scouring, bleaching, mercerizing, dying, printing and finishing. Depending on the final products, textile factories follow all or several of above stages of the production process [4]. It was demonstrated that up to 50% of dyes are lost after the dyeing process and disposed of in the effluents [5]. These wastewaters commonly contain moderate concentrations of dyestuffs combined with large amounts of aqueous waste, which becomes a significant environmental problem. The presence of very small amounts of dyes in water is highly visible which seriously affects the aesthetic quality, water transparency and dissolved oxygen concentration in water bodies, resulting in deterioration of aquatic environment [4]. In addition, a number of studies have demonstrated mutagenic activity in effluents from textile and dye-related industries [6-9]. This problem is further aggravated in Fez city, Morocco, because the water from the drainage is used directly for irrigation purposes. Therefore, the severity of the problem related to textile wastewater treatment is widely recognized and immediate remedial measures are required to tackle the problem in Morocco. Different methods of wastewater treatment developed so far have been evaluated for possible application in the treatment of textile wastewater to remove colour and biodegradable organics. Chemical and physical methods including adsorption, coagulation–flocculation, advanced oxidation and electrochemical methods are very efficient in color removal [10-14]. These methods are quite expensive and have posed operational problems. In this study, we have used an aerobic sequencing batch reactor (SBR) at a laboratory scale for treating textile wastewater collected from a dying industry in Fez city-Morocco, in order to remove the organic matter and mineral matter (carbon, nitrogen, and phosphorus) and toxic micropollutants (in particular dyes) from these effluents. The biological treatment of textile wastewater using SBR system seems to be a cost effective alternative to the physical-chemical and photochemical methods which have various limitations in addition to its efficiency in removing colour and COD. SBR processes are known to save more than 60% of expenses required for conventional activated sludge process in operating cost [15]. The success of SBR technology depends upon the great potential provided by the possibilities of influencing the microbial system in the SBR and also upon the fact that SBRs are comparatively easy to operate and are cost efficient [16]. Previous studies have indicated the success of SBR in achieving the complete biodegradation of azo dyes [17-19]. SBR has been successfully applied for the treatment of domestic wastewater, medium and lower strength land fill leachates, simulated dye wastewaters and contaminated soils [16,20]. Therefore, the main objective of this study was to investigate the efficiency of an aerobic SBR in removing colour, COD and suspended solids from a real textile wastewater.

Materials and Methods

Textile Wastewater

Real textile wastewater collected from a textile mill situated in Fez (industrial district of Sidi Brahim, Fez, Morocco) was used for this study. The composite effluent resulting from different textile manufacturing process is drained in a bar screen for retaining suspended solids then collected in a basin to reduce wastewater temperature and to keep effluent homogenous. Samples were collected and stored at 4°C.

Sequencing Batch Reactor (SBR)

An aerobic SBR was operated during 270 days in order to remove organic matter and color. The lab-scale SBR, illustrated in [Fig-1] was made of Pyrex glass had a total volume of 4 L and the operating liquid volume was 3 L. Tubes were inserted into the top of the reactor to ensure the filling and withdrawal of the effluent using peristaltic pumps. An air compressor was used for aeration with airflow of 1 L min^{-1}. The bioreactor was operated in a sequencing batch mode at room temperature (25°C). The total cycle period was 24 h: the reaction took place in 22 hours, the settling in 1 hour 30 minutes and the withdrawal and filling of the treated effluent and influent in 30 minutes.

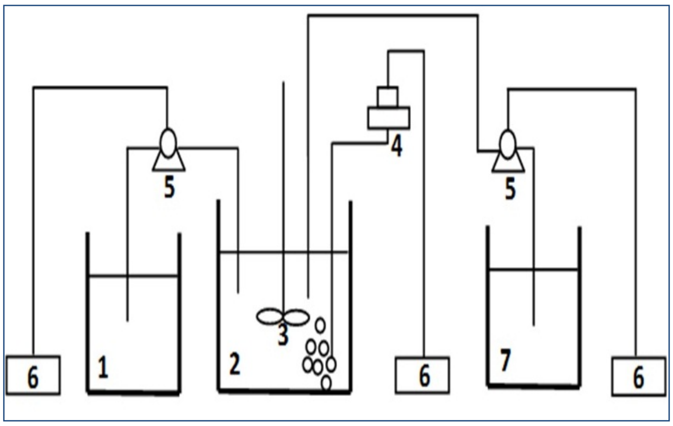

Fig. 1- Lab-scale SBR system operating with real textile effluent.

1- Real textile wastewater, 2- Bioreactor, 3- Stirrer, 4- Air compressor, 5- Peristaltic pump, 6- Timer, 7- Treated textile wastewater

The sequence of the SBR operation was controlled by programmed timers. The influent was delivered to the bioreactor at a flow rate of 0.9 L d^{-1} until day 117, then at a rate of 2.2 L d^{-1} until the end of the experiment. The OLR was 0.3 Kg COD m^{-3} d^{-1} until day 117 then was increased to 0.7 Kg COD m^{-3} d^{-1} until the end of the experiment. Sludge age was adjusted by withdrawing certain volume of the mixed liquor and was varied between θ_C = 7 days and θ_C = 30 days during the experiment.

Inoculum

The reactor was seeded up to 1/6 of the operating liquid volume with aerobic biological sludge obtained from the aerobic basin of the Akrach sewage treatment plant (Rabat, Morocco). Initially, the activated sludge was acclimated to real textile wastewater for 15 days. After stable performance was achieved, the reactor was operated continuously for a period of 270 days.

Analytical Methods

Temperature, pH, electric conductivity (EC), Chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), suspended solids (SS), total dissolved solids (TDS), mixed liquor volatile suspended solids (MLVSS), nitrates ($N\text{-}NO_3^-$), ammonia ($N\text{-}NH_4^+$), orthophosphates ($P\text{-}PO_4^{3-}$) and dissolved oxygen were analyzed according to the Standard Methods for the Examination of Water and Wastewater [21]. COD was determined according to standard micro method with a COD meter HACH and BOD_5 with the manometric method using a respirometer OXI TOP IS6 [21]. Quality control was ensured by using standards as well as duplicates. Heavy metals were determined by Inductively Coupled Plasma-Absorption Emission Spectroscopy (ICP-AES). The color of raw and treated textile wastewater was determined spectrophotometrically using UV -visible spectrometer (Jenway 6405 UV/Vis). The samples were filtered by micro fiber filter and centrifuged at 7000 rpm for 10 min prior to absorbance measurements [22, 23]. Color removal was determined based on the maximum absorbance of UV visible spectrum using the [Eq-1].

Where: A_0 is maximum absorbance value of real textile wastewater at visible wavelength and A is maximum absorbance value of treated textile wastewater (TTW) after SBR process.

Results and Discussion

Characteristics of Real Textile Wastewater

Real textile wastewater physicochemical characteristics are shown in [Table-1]. The mean and standard deviations were calculated using 10 different samples during the experimental period. Briefly, we can say that RTW is characterized by, high load of organic matter resulting in an average COD concentration of 1045 mg L^{-1}, high SS content (3160 mg L^{-1}) and high electric conductivity (4220 µS cm^{-1}). High salinity was reflected by average TDS concentration of 2310 mg L^{-1}. RTW presented neutral pH (7.3) and low dissolved oxygen (0.8 mg L^{-1}). $N\text{-}NH_4$ and $P\text{-}PO_4^{3-}$ averaged 1.12 mg L^{-1} and 1.5 mg L^{-1} respectively. The ratio DBO_5/COD was 0.32, which means that the biodegradability of the effluent is low [21]. The effluent contained an appreciable concentration of divalent cations Mg^{2+} (27.37 mg L^{-1}) and Ca^{2+} (104.26 mg L^{-1}). Heavy metals Cu, Cd and Cr were found in less than 0.01 mg L^{-1} concentration except Zn and Ni (mean concentrations were 217 mg L^{-1} and 0.14 mg L^{-1} respectively). Finally, the COD/N/P ratio averaged 104/0.11/0.15 and showed that the textile effluent contained very low amounts of nitrogen and phosphorus. It was noticed that this ratio was variable according to the effluent content. However, nitrogen and phosphorus deficiency could be identified but no nutrient was added to the bioreactor during the experiment.

It can be seen that the composition of the textile effluent used in this study varied widely and suffered from low biodegradability and high electric conductivity. This showed that high variability in the effluent characteristics, which is due to the variety of materials and techniques used in the production processes, would not be the only obstacle for the good operation of the SBR system. The deficiency in nitrogen and phosphorus in the effluent is another obstacle for the good operation of the bioreactor.

Table 1- Characterization of real textile wastewater

Parameter	Min	Max	Mean (± SD)	M.Q.D.S
pH	6.48	8.23	7.3 ± 0.2	6.5-8.5
Electic conductivity (EC) (µS cm^{-1})	2750	13670	4220 ± 324	
COD (mg L^{-1})	361	2500	1045 ± 127	500
BOD_5 (mg L^{-1})	20	400	340 ± 8	100
Suspended solids (SS) (mg L^{-1})	310	11000	3160 ± 120	50
Total dissolved solids (TDS) (mg L^{-1})	200	3220	2310 ± 760	
P-PO_4^{3-} (mg L^{-1})	0.08	4.03	1.5 ± 0.01	
N-NH_4^+ (mg L^{-1})	0.05	10.68	1.125 ± 0.002	
N-NO_3^- (mg L^{-1})	0.2	27.61	2.24 ± 0.31	
Dissolved oxygen (mg L^{-1})	0	1.2	0.8 ± 0.04	
Mg^{2+} (mg L^{-1})	0.10	57.02	27.37 ± 23.62	
Ca^{2+} (mg L^{-1})	34	263	104.26 ± 99.25	
Zn (mg L^{-1})	21.3	452	271 ± 2.1	5
Ni (mg L^{-1})	0.01	0.5	0.14 ± 0.03	0.5
Cu (mg L^{-1})	-	-	< 0.01	1
Cr (mg L^{-1})	-	-	< 0.01	2
Cd (mg L^{-1})	-	-	< 0.01	0.2

Min: minimum; Max: maximum; SD: Standard deviation; M.Q.D.S: Moroccan Quality Discharge Standards

SBR Performance

COD Removal

COD removal by the SBR is reported in [Fig-2], where the influent wastewater and the treated effluent concentrations for each OLR are indicated. The experiment was repeated three times and the results of the triplicates are given in the figure. At the OLR of 0.3 kg COD m^{-3} d^{-1}, the COD removal efficiency was low for sludge age 7 days and reached 56% when it increased to 93% at sludge age of 30 days. This resulted in a treated effluent containing 380 mg L^{-1} COD and 199 mg L^{-1} COD respectively. The flow rate of the feed was 0.9 L d^{-1} and MLVSS was 1.19 ± 0.11 mg L^{-1} and 2.45 ± 0.21 mg L^{-1} at sludge age of 7 and 30 days respectively. When the OLR was increased to 0.7 kg COD m^{-3} d^{-1}, the flow rate of the feed increased to 2.2 l d^{-1}. Consequently, the COD removal efficiency falling down to 27% at sludge age of 7 days and the COD concentration was high in the treated effluent (577 mg l^{-1}). For sludge age of 30 days, the COD concentration in the treated effluent attained 131 mg l^{-1} and the COD removal efficiency reached its highest value (98%). The MLVSS was 1.04 ± 0.24 mg L^{-1} and 5.47 ± 1.24 mg L^{-1} at sludge age of 7 and 30 days respectively. Compared to the Moroccan discharge standards, both treated effluents COD at the OLR of 0.3 (173 mg L^{-1}) and 0.7 kg COD m^{-3} d^{-1} (131 mg L^{-1}) for sludge age of 30 days were under the limit value (500 mg L^{-1}). From the obtained results, it's evident that the OLR and sludge age affect the SBR performance. At the OLR of 0.3 kg COD m^{-3} d^{-1}, the textile effluent ratio COD/N/P was about 117.6/0.245/0.123 which reflected the low quantity of nitrogen for biomass growth in comparison to carbon. While the effluent ratio COD/N/P was about 803/1.63/1.18 at OLR of 0.7 kg COD m^{-3} d^{-1}. This explained lower COD removal recorded at sludge age of 30 days (93%) at OLR of 0.3 kg COD m^{-3} d^{-1} in comparison to the value recorded at the same sludge age at the OLR of 0.7 kg COD m^{-3} d^{-1} (98%). Concerning sludge age of 7 days, COD removal at both OLR was very low in comparison to the values recorded at sludge age of 30 days. This can be due to the low biomass concentration in the bioreactor and the toxic effect of the effluent.

It appeared clearly that the performance of the SBR in removing COD was depending upon the environmental conditions in the reactor and overall upon the MLVSS concentration. The specific effect of MLVSS concentration on COD removal was then further analyzed. [Fig-3] shows that the COD concentration in the treated effluent increased and the COD removal efficiency decreased when the MLVSS concentration decreased in the reactor. Up to 1190 mg L^{-1} MLVSS, the COD concentration in the treated effluent averaged 380 mg L^{-1} and 56% COD removal efficiency was achieved (OLR = 0.3 kg COD m^{-3} d^{-1}, θ_C = 7 days). At MLVSS concentrations higher than 5000 mg L^{-1} (OLR = 0.7 kg COD m^{-3} d^{-1}, θ_C = 30 days), the treated effluent COD concentration averaged 98 mg L^{-1} (98% COD removal efficiency). Consequently, these results show the strong inhibitor effect of the lowest MLVSS levels on the performance of the bioreactor. The microbial consortium was unable to adapt efficiently to the highest toxicity levels.

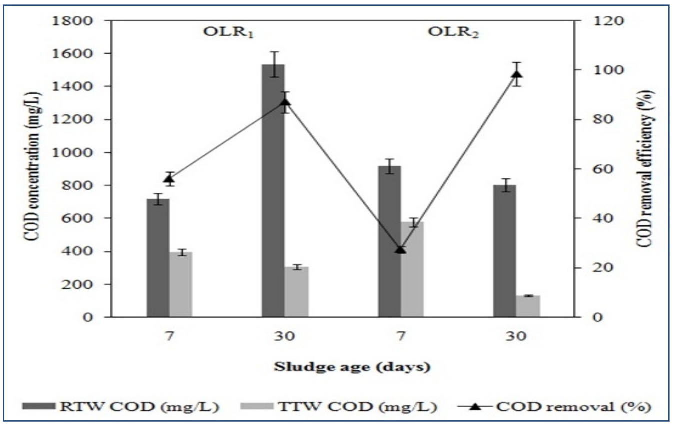

Fig. 2- Variation of COD concentration in RTW and TTW and variation of the COD removal efficiency with sludge age and OLR (OLR_1 = 0.3 kg COD m^{-3} d^{-1}, OLR_2 = 0.7 kg COD m^{-3} d^{-1}) during the operation of the aerobic SBR.

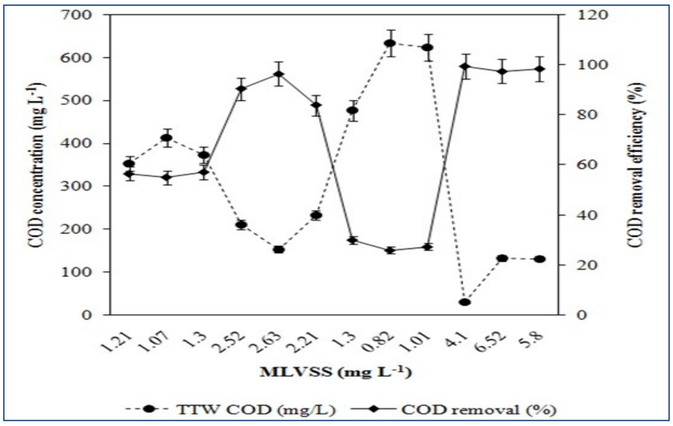

Fig. 3- Variation of COD concentration in TTW and COD removal efficiency with MLVSS concentration during the operation of the aerobic SBR.

From the results obtained, the performance of SBR showed better performance compared to other reported works on aerobic SBR. Only 64% COD removal was achieved in treatment of complex chemical wastewater at an organic loading rate of 0.8 kg COD m^{-3} d

$^{-1}$ and reaction (aerobic) phase of 23 h [16]. It is evident from the results, that with decrease in sludge age and MLVSS the COD removal rate was reduced. The higher COD removal can be expected when the bioreactor sludge having high microbial activity is used in the reactor [24, 25]. Since, 98% of COD was removed by aerobic organisms, it has to be stated that, the main COD removal phase in the SBR system is the aerobic phase. These results are in agreement with those reported by previous works [24], but contradict the obtained data in the studies carried out by other authors in which they reported the contribution of most COD removal to the anaerobic stage in an anaerobic-aerobic SBR system treated simulated textile wastewater [18,26]. In the light of the experimental results of this study, the optimum OLR and sludge age were determined as 0.7 kg COD m^{-3} d^{-1} and θ_C = 30 days for efficient COD removal.

Color Removal

Color removal performance of SBR was determined by measuring the dye removal rates. [Fig-4] shows RTW and TTW absorbance at 568 nm and color removal with OLR during the operation of the bioreactor. Color removal efficiency decreases with increasing OLR. The maximum decolorization efficiency was obtained as 99.41 ± 1.21% for OLR of 0.3 kg COD m^{-3} d^{-1} at sludge age of 30 days. Lower sludge age adversely affected the color removal. At 7 days sludge age, the efficiency decreased to 86.4 ± 1.3%. The lowest absorbance of TTW at 568 nm (0.004 ± 0.001) was observed at sludge age of 30 days while it was 0.115 ± 0.04 at sludge age of 7 days. Color removal could be achieved by the processes of biodegradation, the adsorption of dyes into microbial flocs, and adsorption followed by biodegradation [27]. Acclimatization of microorganisms for dyes present in RTW may be the reason for higher color removal at sludge age of 30 days. Increasing OLR to 0.7 kg COD m^{-3} d^{-1} affected decolorization. Color removal was 94 ± 1.63% at sludge age of 30 days, and at sludge age of 7 days it decreased to 37 ± 0.2% which was the lowest removal observed. Low color removal at sludge age of 7 days seems to be due to low adsorption onto flocs.

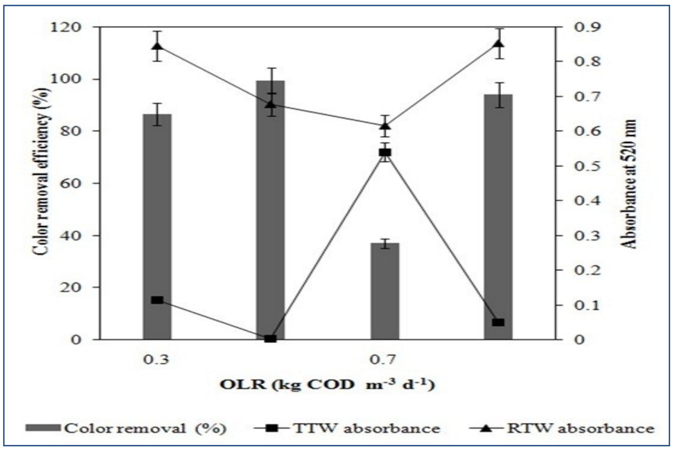

Fig. 4- Evolution of color removal and absorbance of RTW and TTW at 568 nm with OLR during the operation of the aerobic SBR.

From the results obtained, the main color removal was achieved under aerobic conditions during the reaction phase (22 h). The main reason for this result could be the accumulation of aerobic organisms in SBR due to their long term exposure to aerobic conditions in the system. This might have enhanced the decolorization activity of aerobic biomass. It has been reported that azo dyes could be biodecolorized under aerobic conditions with the help of oxygen catalyzed azoreductase enzymes [28,29]. However, the studies of the anaerobic–aerobic sequential textile wastewater treatment system indicated that color removal occurred mainly in an anaerobic environment while the contribution of aerobic phase on color removal was negligible. The same result was observed for decolorization of Remazol Black B in the SBR system and reported around 70% color removal in anaerobic phase while it was maximum 12.8% in aerobic phase [30]. Similarly, it was reported that dyestuff removal of 90% takes place under anaerobic conditions and aeration provides a slight color removal of SBR operated with a textile dyestuff (Remazol Rot RR) containing synthetic wastewater [31].

In summary, color removal takes place under aerobic conditions and aeration provides high color removal by aerobic adequate population in the bioreactor. The performance of aerobic SBR showed good results in term of color removal in comparison to other reported works on anaerobic-aerobic SBR.

SS Removal

Evolution of suspended solids in the RTW and TTW of the SBR is shown in [Fig-5]. The first 22 days were characterized by moderate SS amount in the treated effluent and the removal efficiency was over 90%. Then, the performance of the SBR in removing SS decreased. On day 56, the SS concentration in the outlet reached 1450 mg L^{-1} (52% SS removal efficiency), then decreased to 480 mg L^{-1} (83% SS removal efficiency) at day 63. Then the bioreactor performance in removing SS increased again. The SS removal efficiency was more than 96% over 90 days and reached total removal (100% SS removal efficiency) over 115 days. With change in OLR and MLVSS concentration [Fig-3], the performance of SBR in removing SS fluctuated. A major perturbation occurred after day 140, when the MLVSS concentration decreased, though OLR increased from 0.3 kg COD m^{-3} d^{-1} to 0.7 kg COD m^{-3} d^{-1}. This resulted in the withdrawal of substantial amounts of SS, as shown in [Fig-5]. This resulted in higher amounts of COD in the treated effluent in the days following day 140 [Fig-3]. From day 153 to day 225 of experiment, SS concentration averaged 986 mg L^{-1} (83% removal efficiency), which still indicates high turbidity. This fact can be due to the low mechanical integrity of the flocs, as well as to the high density of salt water [32]. However, after day 225 the SS concentration in treated effluent decreased (SS averaged 433 mg L^{-1}) and the SS removal efficiency averaged 94%. This fact can be explained by the important increase in the biomass concentration (MLVSS averaged 5470 ± 1240 mg L^{-1}) as seen from the [Fig-3].

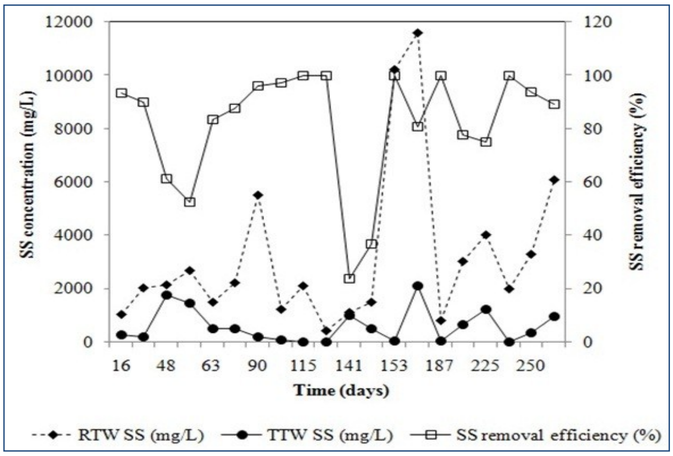

Fig. 5- Evolution of SS concentration in the RTW and TTW and evolution of SS removal efficiency during the operation of the aerobic SBR.

Conclusion

This study proved the efficiency of aerobic SBR in treating real textile wastewater when operated at optimized conditions. The characteristics of RTW showed low biodegradability, high organic loading and high electric conductivity. In addition, this effluent appeared to be highly variable depending on production process. The biomass concentration, the organic loading rate and sludge age appeared to be the main factors that affected the reactor's performance during the experiment. The COD, color and SS removal efficiencies increased when biomass concentration increased, sludge age increased and OLR decreased. Optimum removal efficiencies were attained under a low OLR of 0.3 kg COD m^{-3} d^{-1}, 30 days sludge age and biomass concentration of 2450 mg L^{-1}. COD, color and SS removal efficiencies attained 93.28, 99.41 and 99.9% respectively. In addition, the treated effluent meet the Moroccan discharge quality standards. From the results obtained, the SBR technology appeared to be an adequate solution for the removing of color and organic matter from textile wastewater. Thus, the sequencing batch reactor can be applied on the industrial scale to solve the problem of pollution generated by textile industry. Therefore, treated effluent can be recycled for good purpose, saving the huge quantities of wastewater discharged without any treatment. For this reason, a pilot plant is under construction in the studied textile unit.

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